

S-matrix approach to the Z resonance*

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The proposed e^+e^- -collider FCC-ee aims at an unprecedented accuracy for e^+e^- collisions into fermion pairs at the Z peak, based on about 10^{13} events. The S-matrix approach to the Z boson line shape allows the model-independent quantitative description of the reaction $e^+e^- \rightarrow \bar{f}f$ around the Z peak in terms of few parameters, among them the mass M_Z and width Γ_Z of the Z -boson. While weak and strong corrections remain “black”, a careful theoretical description of the photonic interactions is mandatory. I introduce the method and describe applications and the analysis tool SMATASY/ZFITTER.

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1. Introduction

The FCC-ee project aims at about 10^{13} events in the reaction

$$e^+e^- \rightarrow (\gamma, Z) \rightarrow f^+f^- + (n \gamma) \quad (1)$$

at the Z -boson resonance peak. The analysis in the Standard Model (SM) will deserve 2-loop accuracy; see [4] and many references therein. A promising model-independent alternative is the S-matrix approach [5, 6, 7, 8], originally developed for the analysis of LEP data in 1991/1992 and first applied in 1992 by the L3 collaboration [9, 10]. Later applications at LEP 1, Tristan and LEP 2 are described in [11, 12, 13, 14, 15, 16]. The main problem for a model-independent approach is accuracy. Even if an ansatz is improper, the fit results may nevertheless look precise: Compare the two ansatzes for

* The summary of the material presented at the conference “Matter to the Deepest” in September 2015 at Ustron; also at the FCC-ee meeting in February 2015 at Pisa [2], at the CALC conference in July 2015 at JINR, Dubna [1], and at the HEPKIT workshop in October 2015 at the KIT, Karlsruhe [3].

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the Z -boson propagator,

$$\frac{1}{[s - M_Z^2 + iM_Z \Gamma_Z(s)]} \quad \text{versus} \quad \frac{1}{[s - \bar{M}_Z^2 + i\bar{M}_Z \Gamma_Z]} \quad (2)$$

To a very good accuracy, it holds: $\Gamma_Z(s) \approx s/M_Z^2 \times \Gamma_Z$. The different propagators lead, for one and the same given set of data, to a relative shift of the fitted Z mass [17]: $\bar{M}_Z \approx M_Z - 1/2\Gamma_Z^2/M_Z \approx M_Z - 34 \text{ MeV}$. It is important to note that the “wrong fit” does not have enlarged error bars.

2. Total cross-sections

The ansatz for the scattering amplitude in the complex energy plane comprises, in case of massless fermion pair production, four non-interfering helicity matrix elements:

$$\mathcal{M}^i(s) = \frac{R_\gamma^i}{s} + \frac{R_Z^i}{s - s_Z} + F^i(s), \quad i = 1, \dots, 4. \quad (3)$$

The pole terms have complex weights R_Z and R_γ , the latter corresponding to the photon, and the background $F(s)$ is an analytic function:

$$F^i(s) = \sum_{n=0}^{\infty} F_n^i(s/s_0 - 1)^n \quad (4)$$

Beware: Eqn. (3) contains the photon pole R_γ^i/s , where R_γ^i will be assumed to have a (known) s -dependence. A second pole besides the Z is mathematically not consistent, because a Laurent series has one single pole only. In fact, one has to understand the term $R_\gamma^i(s)/s$ as part of the background term $F(s)$. Such rewritten, it reads in fact:

$$\frac{R_\gamma^i(s)}{s} = \sum_{n=0}^{\infty} R_n^i(s/s_0 - 1)^n \frac{1}{s_0} \left[1 + \frac{s_0 - s}{s_0} + \left(\frac{s_0 - s}{s_0} \right)^2 \dots \right]. \quad (5)$$

The photon pole has to be understood as part of the background terms; but once it is known as part of QED corrections, one may separate it from the rest of background and can take its knowledge explicitly into account.

An analysis of the Z line shape will use the effective Born cross section

$$\sigma_T(s) = \sum_{i=1}^4 \sigma^i(s) = \frac{1}{4} \sum_{i=1}^4 s |\mathcal{M}^i(s)|^2. \quad (6)$$

Further, the $\sigma_T(s')$ has to be folded with a flux function in order to comprise in $\sigma_T(s)$ also QED corrections [18, 19, 20]:

$$\sigma_T(s) = \frac{4}{3}\pi\alpha^2 \int \frac{ds'}{s} \left[\frac{r^\gamma}{s'} + \frac{s'R_T + (s' - \bar{M}_Z^2)J_T}{(s' - \bar{M}_Z^2)^2 + \bar{M}_Z^2\Gamma_Z^2} + \dots \right] \rho_{ini}^T(s'/s). \quad (7)$$

Here, two real parameters besides M_Z and Γ_Z appear, the R_T arising from the Z pole term and J_T from the γZ -interference.

The radiation from the final state may be absorbed into ρ_{ini}^T , and initial-final state interferences can be taken into account by an analogue formula to (7) with a slightly more complicated structure:

$$\sigma_{T,int}(s) = \int ds' \sigma(s, s') \rho_{int}^T(s'/s). \quad (8)$$

A precise description of QED, not only in the running QED coupling, but also in the flux functions $\rho_{ini}(s'/s)$ and $\rho_{int}(s'/s)$ is mandatory. We mention already here that for the forward and backward cross-section parts σ_F and σ_B different flux functions apply, and so the corrections to σ_{F-B} are different from those to σ_{tot} . Finally, it is recommended to use for the predictions of the QED corrections a sophisticated, flexible, well-tested tool like ZFITTER [21, 22, 23, 24]. The recommended interface is the Fortran package SMATASY/ZFITTER [7]. The latest version of SMATASY runs with ZFITTER v.6.42 and is due to M. Grünewald [8]. Although it is not explicitly pronounced by the authors, the copyright conditions are the same as those for ZFITTER. Please notice that the valid CPC-licence conditions [25] do not always guarantee that they are respected [24, 26, 27, 28, 29, 30, 31, 32], and thus we think that it is appropriate to remind here of the importance of the software authors' rights and rules of Good Scientific Practice (Appendix A).

3. Asymmetries

Born asymmetries $A_{FB} = \sigma_{FB}/\sigma_T$, $A_{pol} = \sigma_{pol}/\sigma_T$, $A_{LR} = \sigma_{LR}/\sigma_T$, as ratios of two Laurent series, are simple Taylor series. QED corrections lead to few simple correction factors; we reproduce two of them:

$$A_{LR}^{QED}(s) = A_{0,LR}^{Born} + c_{1,T}(s) A_{1,LR}^{Born} \left(\frac{s}{M_Z^2} - 1 \right) + \dots, \quad (9)$$

$$A_{FB}^{QED}(s) = c_{0,FB}(s) A_{0,FB}^{Born} + c_{1,FB}(s) A_{1,FB}^{Born} \left(\frac{s}{M_Z^2} - 1 \right) + \dots \quad (10)$$

The real constants A_0 and A_1 are of experimental relevance:

$$A_{0,A} = \frac{R_A}{R_T}, \quad A_{1,A} = \left[\frac{J_A}{R_A} - \frac{J_T}{R_T} \right] A_0, \quad A = FB, pol, LR. \quad (11)$$

The QED corrections are contained in smooth set-up dependent, *model-independent* factors $C(s)$:

$$c_{0,FB}(s) = \frac{C_{FB}^R}{C_T^R}, \quad c_{0,T}(s) = 1, \quad c_{1,A}(s) = c_{0,A} \frac{C_T^J}{C_T^R}, \quad a = T, FB. \quad (12)$$

As examples, we reproduce $C_T^R(s)$ and $C_{FB}^R(s)$:

$$C_A^R(s) = \int dk \rho_{ini}^A(s'/s) \frac{s' R_A}{s R_A} \frac{(s - \bar{M}_Z^2)^2 + \bar{M}_Z^2 \Gamma_Z^2}{(s' - \bar{M}_Z^2)^2 + \bar{M}_Z^2 \Gamma_Z^2}, \quad a = T, FB. \quad (13)$$

4. Applications

The described model-independent approach allows experimental fits to the mass and width of the Z boson which are, in accuracy, competitive to the Standard Model approach. The minimal number of data points (in s) will be five, as may be seen from (7). There is a correlation of Z peak position s_{peak} , the Z mass value, and the γZ interference term J_T :

$$\Delta\sqrt{s_{peak}} = \Delta\bar{M}_Z + \frac{1}{4} \frac{\Gamma_Z^2}{\bar{M}_Z} \Delta\left(\frac{J_T}{R_T}\right). \quad (14)$$

Any misidentification of J_T leads to a correlated systematic shift of \bar{M}_Z . In the Standard model, the J_T is a derived quantity and thus fixed, while here it is a floating quantity - if we do not decide to fix it “by hand” or by other data. As a consequence, the error bars in the strict S-matrix approach for \bar{M}_Z will be systematically a bit bigger than in the SM approach. For further discussions, we refer to the literature quoted and to [33, 9, 34, 1]. Whether the S-matrix approach can be useful at the FCC-ee deserves a detailed investigation on the approximations made in the SMATASY/ZFITTER toolkit which have not been discussed here.

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Appendix A

Good Scientific Practice and software

As quoted above, it happens that the rules of Good Scientific Practice are violated when software is concerned. The reasons root deeply in history. For decades, software was not considered as a genuine result of scientific work, but mere as an auxiliary work with no value by itself. This changed with its rising complexity. But until today, in almost all of the official documents on Good Scientific Practice there is mentioning of texts, figures, ideas, data, but no mentioning of software. And a need of its protection against misuse - by lack of attribution or by improper use - is questioned, especially by non-experts .

International academic fundamental research relies on universal principles and ethical rules, and on national legal regulations. We are seekers of the truth. One of our most important principles is honesty. Society has to trust us in our doings because an independent control is, due to the complexity of our work, impossible. We researchers carry the responsibility to prevent and, in case it happens, sanction fraud in science. Fraud destroys the balance of competition and cooperation. It also destroys the trust, and it finally destroys the contract of society and science.

Academic research, and we are part of that, is distinguished from other research by the need of correct attribution:

- *Attribution* of a scientific achievement to those who made it.
Often by a proper citation. Other proper attributions are possible.

There is no need to explain why proper attribution is substantial. Violations are called plagiarism. A proper attribution informs on:

- *What was done? Who did it? How important is it?*

In case of ethical or legal problems, seek cooperations and not confrontations. Questions have to be answered, in this order:

- *Facts:* What are the initial facts? Investigate carefully.
Rules: Are there violated rules? Seek a healing by negotiations.
Sanctions: In case. Are there sanctions foreseen? By whom?

A round table discussion on “Open-source, knowledge sharing and scientific collaboration” at ACAT2013 is summarized in [32]. An important point is the authors’ right to set “conditions of use”, often formalized in licence agreements. In scientific practice, they replace law - if they are respected. We use here the CPC-licence [25], which is unfortunately questioned by a variety of colleagues and institutions. If this will become a common practise

no scientist will be willing to develop a software to be shared by the community. Other well-known licence model families are GPL licences (Gnu public licences, not ideal for academic attributions, although often recommended for software) and CC licences (Creative Commons licences). To respect licences as valid “conditions of use” is essential because there is no international copyright law. With no doubt – it would be extremely difficult to authors to defend rights at a court. The big international scientific centers and all the national science organizations are asked not only to set the rules, but also to defend them.

Note added on 14 October 2016 for submission to the hep-ph archive

All the people we used to know
 They're an illusion to me now
 Some are mathematicians
 Some are carpenters' wives
 Don't know how it all got started
 I don't know what they're doin' with their lives
 But me, I'm still on the road
 Headin' for another joint
 We always did feel the same
 We just saw it from a different point
 Of view
 Tangled up in blue

Text © Bob Dylan Music Co. (1974)
<http://bobdylan.com/songs/tangled-blue>

The present text has been published in the proceedings of the Ustron meeting “Matter to the deepest” in Acta Physica Polonica vol. 46 (2015) No 11, p. 2235, with the affiliation Königs Wusterhausen, Germany. This is one of the places where I live and work.

In 2015, I gave four quite similar presentations of the topic at meetings at Pisa, Dubna, Ustron, Karlsruhe. For the presentation at Karlsruhe [3] I asked, on 2 October 2015, the scientific representative of DESY Dr. H. Dosch for the approval of the slides. I got the written approval to give the talk (as it was submitted) by email on 7 October 2015: “...im Auftrag von Herrn Dosch und in Abstimmung mit Herrn Mnich richte ich Ihnen hiermit die Genehmigung Ihrer Slides aus.” Unfortunately, the approval was given the day after the talk, and thus there are

two versions of it at the conference webpage, with different affiliations,
<https://indico.cern.ch/event/369827/contributions/875702/attachments/1166637/1682217/2-riemann.pdf>
and <https://indico.cern.ch/event/369827/contributions/875702/attachments/1166637/1683306/2-riemann.pdf>

On 12 October 2015, I asked the scientific representative of DESY for the permission to publish the proceedings version of the slides as a DESY Red Report (filename: 2015-ustron-proc-riemann-sMatrix-rR.pdf, 13 Oct 2015). The text was not accepted for publication (Dr. J. Mnich, 18.11.2015), and on 6 December 2015 I appealed to the ad-hoc publication commission of DESY (Dr. M. Köhler, Dr. C. Stegmann, Dr. M. Diehl, established on 17 December 2015). The commission's report is dated four months later, on 21 April 2016.

The commission decided that the present text would be appropriate for publication if certain changes would be undertaken. I refused, and the text did not get the approval as a DESY Red Report.

The contents of my talk on "S-matrix approach to the Z resonance" summarizes the publications on the S-Matrix approach to the Z resonance from 1991 till now. The motivation is to have a mini-review for later use with respect to physics studies for the ILC. With the ILC, one aims at per mille accuracy of many observables, and many of the analysis tools have to be re-analyzed therefore. Including the S-matrix analysis tools.

In the meantime, we finished (in August 2016) a 2-loop project on the weak mixing angle in the standard model related to the Zbb vertex; see: I. Dubovyk, A. Freitas, J. Gluza, T. Riemann, J. Usovitsch, PLB 762 (2016) 184, <http://dx.doi.org/10.1016/j.physletb.2016.09.012>, preprint KW 16-002, <http://arxiv.org/abs/1607.08375>.

I could not understand one point – how to get the pseudo-observable A_{FB} , and thus $\sin^2 \theta_W^b$, from realistic cross sections, when observing the correct ansatz for the weak amplitude in the standard model as demanded by analyticity, causality, unitarity and gauge invariance. And then I understood: The answer is the S-matrix approach to realistic observables.

Not interpreted as an alternative to perturbation theory, as I did so far, but in conformity with perturbation theory.

Why did I not make the text changes in the manuscript in fulfillment of the proposals of the DESY commission?

1. References [21,23-29] were demanded to get shortened to [24,30,31]. (The references in the commission's letter refer to a text slightly different from the APP text.) The change might have been tolerable.

2. Webpage [21] <http://sanc.jinr.ru/users/zfitter> was demanded to be replaced by the archived webpage <http://dx.doi.org/10.3204/zfitter.education> held at the DESY domain.

The change is not acceptable.

The ZFITTER webpage at JINR is the project page of the ZFITTER project, and it has to be dynamic as the project is dynamic, and it has to be under the authorship of the project authors.

3. Ref. [29]: Carminati, Perret-Gallix, Riemann, "Summary of the ACAT 2013 round table discussion: Open-source, knowledge sharing and scientific collaboration", J. Phys. Conf. Ser. 523, 012066, <http://dx.doi.org/10.1088/1742-6596/523/1/012066>, <http://arxiv.org/abs/1407.0540>, Red Report DESY 14-079. This reference is demanded to be omitted.

The reason is not made clear.

I did not fulfill demands 1. to 3. of the DESY publication commission, and the publication was not approved by the scientific representative of DESY. My written appeal to the scientific representative of DESY to ignore the recommendations of the DESY publication commission was not answered.

As a result of the developments described to my best knowledge, the publication was not approved with a DESY affiliation.

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